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THE EFFECTS OF AIR POLLUTION ON PROVENANCES OF SCOTS PINE AND NORWAY SPRUCE IN NORTHERN FINLAND

SATU HUTTUNEN

SELOSTE:

ILMAN SAASTUMISEN VAIKUTUS MÄNTY- JA KUUSIALKUPERIEN VIIHTYMISEEN POHJOIS-SUOMESSA

Saapunut toimitukselle 1977-11-16

The success of certain pine and spruce provenances from Northern Finland was studied in a tree damage area occasioned by air pollution in the town of Oulu over the period 1972—76, the pine strains from more northerly and easterly areas and the spruce strains from the immediate vicinity of the site itself being observed to thrive best. The results point in a similar direction to those of other comparable experiments, except that the mortality rate amongst the saplings was exceptionally high and the proportion of healthy saplings in good condition was found to be unusually low. Structural properties suggestive of resistance to pollution were observable selectively in certain provenances, these including the xeromorphy of needles or a thickness of the epidermis. The chief cause of mortality amongst the sapling was found to be the damage infilicted by pollution during the winter, while that arising in the summer months was relatively slight. The results of this experiment may be made use of in selecting native coniferous saplings for planting in urban or industrial environments.

INTRODUCTION

The major differences between plant species in their susceptibility to air pollution have been well known for some time, and it has frequently been noted that the effects of pollutants on one of the most sensitive groups, that of the coniferous trees, may fluctuate widely, with substantial differences in survival capacity being manifested between different provenances and even different individuals of the same species. These have been shown to be due to differences in physiological resistance to pollution, in structural defences against penetration by toxic substances or in genetic sensitivity (Vogl et al. 1965, Vogl 1964, Börtitz 1964). One such species displaying widely varying sensitivity and resistance properties is *Pinus strobus* (Berge 1959, Wenzel 1959, 1969, Berry & Hepting 1964, Schönbach et al. 1964, Björkman 1970, Stairs & Houston 1970). Similarly, differences in sensitivity within the one species have been demonstrated in numerous laboratory and some field experiments in the case of both the Norway spruce (e.g. KELLER 1976) and Scots pine (VOGL 1964).

The resistance involved in these instances may be broadly of one or other of two types: resistance to penetration by toxins, or the resistive capacity to eliminate toxins which have penetrated the organism. Nevertheless, by no means all the properties responsible for such differentials between provenances or individuals have yet been identified, though clearly both physiological factors and also the capacity for adaptation to extreme environmental conditions, e.g. to wintering, must be implicated. Such effects as a reduction in resistance to cold, increased transpiration, etc. have been noted in connection with air pollution (BÖRTITZ 1968, STEIN & DÄSSLER 1968). These disturbances are clearly of considerable importance as far as the winter effects of air pollution are concerned, and more recent work has established that very much smaller quantities of toxins are required to inflict damage during the winter (MATERNA 1974) and that the damage inflicted under winter conditions may be exceptionally severe (HAVAS 1971, HUTTUNEN 1974, 1975).

Research into the resistance to air pollution of coniferous species is frequently directed at coniferous stands within urban areas, the susceptibility of which is compounded by their genetic impoverishment (cf. STERN & ROCHE 1974). One approach to the study of the occurrence of inter- or intra-species variation in this respect is by means of laboratory trials performed on saplings. The significance of such tests is limited, however, and they are only valid with certain reservations. For instance, WENTZEL (1969) considers them doubtful value in comparison with field trials, since they may lead to entirely the opposite results from those obtained in the field. The immission dynamics of the plants also play an important role in this connection, as a given species may be exctremely sensitive to short-term effects of small doses, or in some cases *vice versa*. More reliable results may be obtained, though only over longer periods of time, by means of field tests with conifers of different provenance, for example. One method frequently employed for the selection of suitable material for transplantation to pollution sites is the 'trial by ordeal', in which the saplings are reared at a site as close as possible to the final location of the experiment and only the specimens best able to survive are chosen for the final tests (WOLAK 1976).

Relatively little is known still about the effects of air pollution on conifers of different provenance or from different clones, and only a few reports are available from longer-term field experiments (COTRUFO & BERRY 1970, GIERTYCH 1972), the majority of trials having been carried out on saplings of under 5 years or plants just a few weeks old. Considerable fluctuations in the age of maximum sensitivity have been notes in many species (VAN HAUT 1961, BERRY 1971).

The field trials reported here concern the survival of different provanances of pine (*Pinus silvestris* L.) and spruce (*Picea abies* L.) in an area within the town of Oulu where air pollution has inflicted considerable damage of the conifers, killing many. A relatively large number of actul provenance experiments have been conducted on these pine and spruce species, the results of which were of some help in the selection of the material for these specialized trials (KALELA 1937, SARVAS 1964, EICHE 1966, ERIKSSON et al. 1976).

MATERIAL, METHODS AND PURPOSE OF THE EXPERIMENT

Study area

The study area is located within the air pollution tree-damage zone in Oulu, some 1200 m from a chemical factory, downwind in respect of the prevailing wind direction, i.e. to the south and south-east (site 1 in Fig. 1). The area has been described earlier by HAVAS (1971), HAVAS & HUTTUNEN (1972) and HUTTUNEN (1973, 1974, 1975)

The experimental plot was set up in a field which had been abandoned some years earlier, within the suburb of Rusko (65°02'). The plot was ploughed prior to the experiment in autumn 1971 and harrowed in spring 1972. The saplings were then planted at the end of May and early June in the same year. No further intervention was made after this first summer.

The principal toxic substances present in the area during the period from 1971 onwards were the oxides of nitrogen (2 000 tn/yr), sulphur compounds (2 500 tn/yr), ammonium compounds and gaseous fluorine compounds. The fluorine compounds had constituted a far greater problem prior to 1971 (HAVAS 1971), being emitted at a rate of 90 tn/yr compared with 4.4 tn/yr from 1972 onwards. The area of maximum deposition of these industrial waste-products is located between 400 m and 1 400 m of the factory itself (Fig. 1).

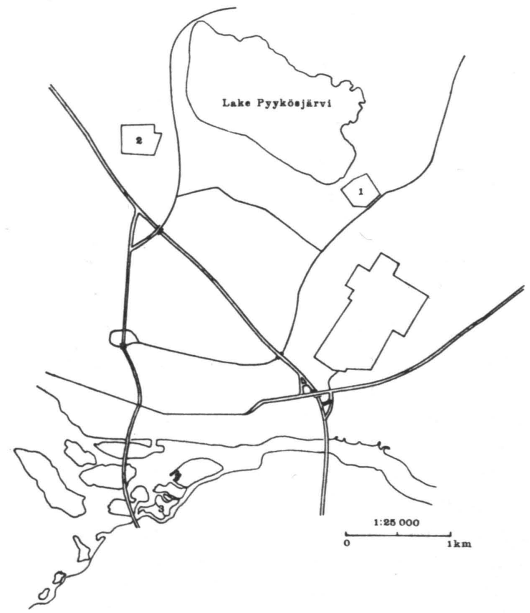

Fig. 1. Transplant sites: 1 = principal site in the suburb of Rusko, 2 = Lauttasuo, the principal source of pollution in the area is the factory indicated on the right-hand edge of the map. 3 = University Botanical Gardens,

Kuva 1. Taimien kasvupaikat: 1 = koekenttä Ruskon kaupunginosassa, 2 = Lauttasuon taimisto, aluetta saastuttaa pääasiassa teollisuusalue kartan oikeassa laidassa. 3 = Kasvitieteellinen puutarha,

Material

It was decided to employ for these experiments saplings raised for forest management purposes, the provenance of which was known only to an accuracy of the commune concerned, being 1 or 2 year saplings from the tree nurseries of Nuojua, Alakärppä and Imari. Such material possess many practical advantages, including its suitability to experimental conditions involving no forest management or other intervention. It is also sufficiently heterogeneous as to provide indications of differences in physiological resistance while still justifying conclusions reached on a genetic basis.

The specimens were chosen at random from among those of Northern Finland provenance, but in any case from no distance greater than 3° lat. away from the site in the case of pine, or 5° lat. away in the case of spruce. A further 1° lat. was added for every 90 m of altitude. Some of the provenances were on the west coast, whereas some were quite definitely located in eastern Finland (Table 1).

The saplings were planted early in the summer of 1972, and a few weeks later the plot was weeded to ensure that the maximum number survived their first summer. Only a small number in fact died at that stage. The plot was subsequently left to develop naturally, the saplings being forecd to compete with the advance of grasses and tree and shrub shoots. From 1973 onwards the increase in height of the saplings was measured annually in the autumn and the mortality rate checked every May. Similarly their needle morphology was examined in respect of size of needle, thickness of the epidermal cells, number of pores and pore size. From 1974 onwards the conditions of the saplings was also estimated each year in May, using a scale of five damage classes:

I = dead
II = in poor condition, over 1/3 of the needls damaged, terminal bud damaged, bent or dead, retarded-growth,
III = satisfactory condition, many damaged needles, nut not as many

Table 1. Communes of origin of the pine, *Pinus silvestris* L., and spruce, *Picea abies* L., specimens employed in the experiment.

Taulukko 1. Kenttäkokeessa käytettyjen mäntyjen Pinus silvestris L. ja kuusten Picea abies L. kotipaikat.

Species — *Puulaji*		Nursery — *Tarha*	Notes — *Huom.*
Pine — *Mänty*			
Pyhäntä	64°10′	Nuojua	n = 55
Kuhmo	64°20′	»	n = 55
Vihanti — Rantsila	64°30′	Alakärppä	n = 55
Hörnefors (Sweden — Ruotsi)	64°30′	»	n = 55
Vaala	64°40′	Nuojua	n = 55
Siikajoki — Raahe	64°50′	Alakärppä	n = 55
Puolanka	64°50′	Nuojua	n = 55
Ylikiiminki	65°10′	»	n = 55
Pudasjärvi	65°37′	Alakärppä	n = 55
Ylitornio	66°20′	Imari	n = 55
Pello	66°45′	»	n = 55
Kolari	67°16′	»	n = 55
Kittilä	67 40′	»	n = 55
Spruce — *Kuusi*			
Puolanka	64°50′	Nuojua	n = 68
Vallinkangas	64 50′	Alakärppä	n = 72
Muhos	64°55′	»	n = 72
Kemi	65 45′	Imari	n = 77
Alatornio	66°10′	»	n = 72
Rovaniemi	66°30′	»	n = 70
Sodankylä	68°33′	»	n = 45

as 1/3, terminal bud imperfect, branching of main stem,

IV = good condition, only some needle damage, terminal and other buds healthy, main stem straight,

V = healthy, at least two years' needles, buds healthy, stem straight and growing vigorously.

This classification is similar to that used by others, including Stefansson & Sinko (1967). No attempt was made here to distinguish damage caused by insects, fungal diseases or small mammals, but the classification was based directly upon total damage, a method which is frequently employed in the evaluation of tree damage inflicted by air pollution (cf. Jokinen 1972, 1975).

Observations on the incidence of needle damage were continued throughout the monitoring period, both by eye and under the microscope, and the needle morphology characteristics of the different provenances were studied on the basis of needle length, number and size of pores and size of the epidermal cells. Local weather and growing conditions were monitored throughout the duration of the experiment.

At the same time as the saplings were planted at this site, control specimens of the same provenance were also planted at Liminka and in the Oulu University Botanical Gardens at Lauttasuo, to provide reference material for the determination of pollution-induced tree damage symptoms, even though no true comparison of the overall state of the transplanted material can be made between these areas which differ so fundamentally in their ecological conditions. In

the same way, it would be impossible to arrange the type of repetition experiment frequently employed in provenance studies in this particular case, since pollution may differ so much from one period of time to another as a result of variations in wind strength and direction. The cultivation of a further set of provenance specimens from seed was begun in Oulu simultaneously with the commencement of the present experiment (Törmälehto 1976).

RESULTS

Mortality

The mean mortality rates for the four years of the experiment may be seen from the table 2. The mean mortality rate for the pine seedlings was over 50 % in the first year and remined relatively high through until the fifth year, whereas that for spruce was lower and more constant throughout.

Table 2. The mortality rates for saplings during different monitoring years.

Taulukko 2. Taimien kuolleisuus eri seurantavuosina.

Year *Vuosi*	Pine — *Mänty*			Spruce — *Kuusi*		
	No living *Kpl eläviä*	No dead *Kpl kuolleita*	Mortality % *Kuoleisuus %*	No living *Kpl eläviä*	No dead *Kpl kuolleita*	Mortality % *Kuoleisuus %*
1972	715	0	0	475	0	0
1973	313	402	56.2	397	79	16.5
1974	167	146	46.6	366	31	7.8
1975	134	33	19.8	340	26	7.1
1976	131	3	2.2	321	19	5.6
	131	584	—	321	155	—

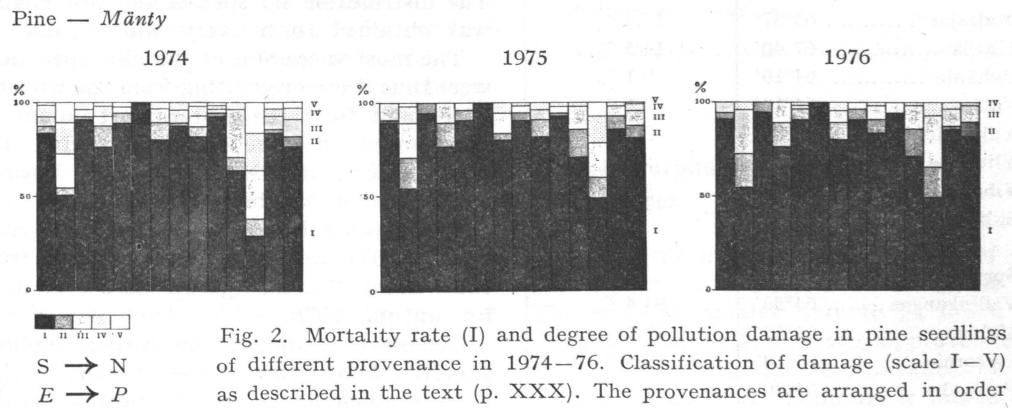

Fig. 2. Mortality rate (I) and degree of pollution damage in pine seedlings of different provenance in 1974—76. Classification of damage (scale I—V) as described in the text (p. XXX). The provenances are arranged in order of latitude from south to north.

Kuva 2. Männyn taimien kuolleisuus (I) ja vaurioituminen eri alkuperissä vuosina 1974—1976. Vaurioluokitus (I—V) tekstissä esitetyn mukainen (vrt. sivu 3), kuvassa eri alkuperät etelästä pohjoiseen leveyspiirien mukaisessa järjestyksessä.

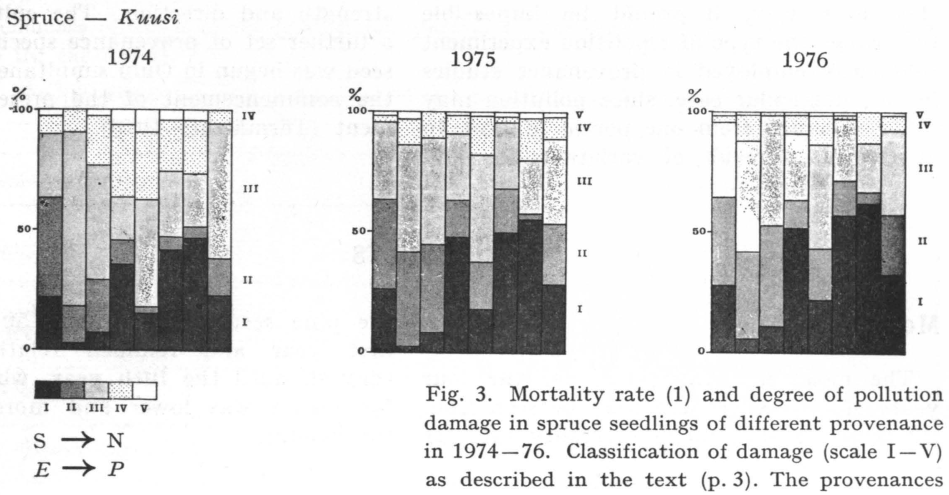

Fig. 3. Mortality rate (1) and degree of pollution damage in spruce seedlings of different provenance in 1974—76. Classification of damage (scale I—V) as described in the text (p. 3). The provenances are arranged in order of latitude from south to north.

Kuva 3. Kuusen taimien kuolleisuus (I) ja vaurioituminen eri alkuperissä vuosina 1974—1976. Vaurioluokitus (I—V) tekstissä esitetyn mukainen (vrt. sivu 3), kuvassa eri alkuperät etelästä pohjoiseen levyspiirien mukaisessa järjestyksessä.

Table 3. Living samplings in the different provenances in autum 1976.

Taulukko 3. Eri alkuperien taimien elävyys syksyllä 1976.

Provenance — *Alkuperä*		% Living samplings *Eläviä taimia*
Pine — *Mänty*		
Kolari	67°16′	50.9 %
Kuhmo	64°20′	45.5 %
Pello	66°45′	29.1 %
Hörnefors	64°30′	23.6 %
Puolanka	64°50′	20.0 %
Pudasjärvi	65°37′	16.4 %
Kittilä	67 40′	14.5 %
Pyhäntä	64°10′	9.1 %
Vaala	64°10′	9.1 %
Ylikiiminki	65°10′	9.1 %
Ylitornio	66°20′	5.5 %
Vihanti—Rantsila	64°30′	5.5 %
Siikajoki—Raahe	64°35′	0 %
Spruce — *Kuusi*		
Vallinkangas	64°50′	94.4 %
Muhos	64°55′	88.9 %
Alatornio	66°10′	77.8 %
Puolanka	64°50′	72.1 %
Kemi	65°45′	48.1 %
Rovaniemi	66°30′	42.8 %
Sodankylä	68°33′	37.8 %

The mortality rates for the different provenances separately are depicted in Figs. 2 and 3 (damage class I). Of the 13 pine provenances, 12 were still represented among the living trees in autum 1976, accounting for a total of 18.3 % of the saplings originally planted, whereas in the case of spruce all 7 provenances were still represented, amounting to 67.4 % of the original stock. The distribution by species and provenance was obtained to be very wide (Table 3).

The most successful of the pine specimens were thus those originating from the extreme north and from the easternmost commune represented in the experiment, and the least successful those from the nearby communes of Northern Ostrobothnia. The entire Siikajoki-Raahe provenance group died in 1974, and only two specimens from the Vihanti-Rantsila group were still alive by autum 1976.

Generally speaking, the spruce saplings survived better than those of pine, having a very much lower overall mortality rate. The most successful strains were those from the immediate vicinity of the site itself, from Vallinkangas and Muhos, and the least successful those from the northernmost communes represented.

The differences between the provenances became evident within the first year, and remained more or less constant throughout the duration of the experiment, the annual mortality rate gradually settling down at a level of a few percent.

Damage classes

The differences between the provenances are to be seen most clearly in the case of damage class I, mortality, whereas the part played by air pollution as a cause of damage may be seen in the absence or relative scarcity of entirely healthy saplings in the various provenance groups. The majority of the living specimens fall into class III, those in satisfactory condition. The differences between the provenances show very similar trends to those identified in the mortality rates, so that those with low mortality rates also featured living saplings which were on average in better condition (see Figs. 2 and 3).

Growth in height

The growth is seen to have been very much stronger in the last summer of the experiment than in earlier ones. The mean height increments recorded in 1974 were 12.8 cm (pine) and 5.1 cm (spruce), in 1975 9.2 cm pine and 4.1 cm spruce, but in 1976 20.7 cm pine and 9.5 cm spruce. The best growth rates among the pines were achieved by those from Hörnefors in Sweden 64°30' and Pello 66°50', and among the spruce by those from Puolanka 64°50' (see Figs. 4 and 5). Standard deviations were varied approximately 9.2—12.3 cm in pine and 6.8—7.8 cm in spruce.

A close correlation is to be noted between height increment and the survival percentage in the case of spruce, in the sense that those provenances showing the strongest growth also survived in larger numbers, but no corresponding correlation appears for pine. (correlations in 1973—1976 r = 0.83—0.93***).

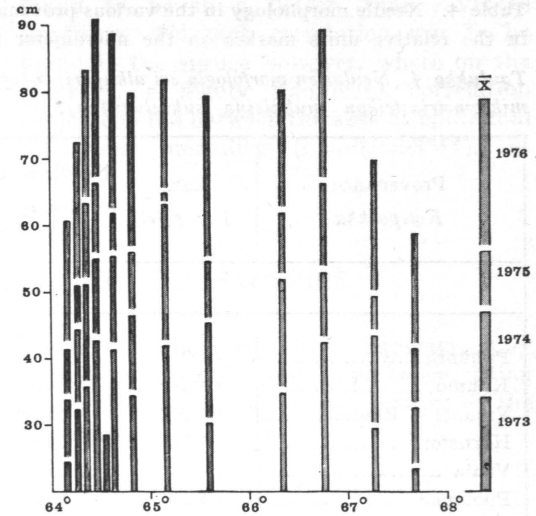

Fig. 4. Annual height increment in pine seedlings of different provenances.

Kuva 4. Männyn taimien vuosittainen pituuskasvu.

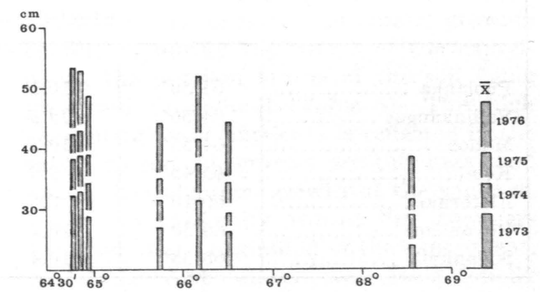

Fig. 5. Annual height increment in spruce seedlings of different provenances.

Kuva 5. Kuusen taimien vuosittainen pituuskasvu.

Needle morphology in the various provenances

The needle morphology properties of the provenances are indicated in Table 4. The smallest needles were to be found on the pines from Pello and Kittilä, provenances which also had the greatest thickness of the epidermal cell layer. Similarly it was in the Pello specimens that the smallest stomata were to be found, while those from Kittilä had the highest number of stomata per

Table 4. Needle morphology in the various provenances (the thickness of the epidermal cells is indicated in the relative units markes on the micrometer used).

Taulukko 4. Neulasten morfologia eri alkuperissä (epidermisolujen paksuus on esitetty mittauksessa käytetyn mikrometriasteikon mukaisina suhdelukuina).

Provenance *Kotipaikka*	Lat. *Lev. piiri*	Needle length *Neulasten pituus mm*	Thickness of epidermis *Epidermin paksuus*	Stomata *Ilmarakoja* No/cm *kpl/cm*	Size of stomata *Ilmarakojen koko* μ m²	No Kpl n
			PINE – *MÄNTY*			
Pyhäntä	64°10′	55.40	8.55	119.4	*2342*	10
Kuhmo	64°20′	54.90	9.0	116.5	2179	»
Vihanti – Rantsila	64°30′	55.90	8.62	*127.3*	2168	»
Hörnefors	64°30′	61.40	9.09	116.5	2159	»
Vaala	64°40′	*69.40*	8.8	118.3	2208	»
Puolanka	64°50′	50.20	9.27	116.7	2287	»
Ylikiiminki	65°10′	52.80	9.02	127.7	2143	»
Pudasjärvi	65°37′	51.20	9.3	108.7	2224	»
Ylitornio	66°20′	52.20	8.82	122.5	2234	»
Pello	66°45′	48.30	9.4	115.9	1999	»
Kolari	67°16′	50.10	9.3	114.3	2135	»
Kittilä	67°40′	48.80	*9.4*	*134.9*	2258	»
			SPRUCE – *KUUSI*			
Puolanka	64°50′	10.1	8.2	110.1	1858	10
Vallinkangas	64°50′	*13.6*	8.3	112.2	*1879*	»
Muhos	64°55′	10.3	8.7	110.1	1648	»
Kemi	65°45′	9.9	8.6	110.0	1515	»
Alatornio	66°10′	8.6	*9.5*	111.8	1629	»
Rovaniemi	66°30′	10.2	9.4	111.7	1448	»
Sodankylä	68°33′	10.4	9.2	*113.2*	1748	»

needle. An examination of the distribution of these morphological characteristics in the light of the differential survival rates for the provenances reveals that the Kolari strain, which was the most successful, possessed relatively small needles with relatively few stomata of small dimensions, while the epidermal cells had comparatively thick cell walls. Correspondingly, the next most successful provenance similarly had relatively small needles with few stomata of smallish dimensions, but the epidermis was relatively thin by comparison with the other groups. When ordered with respect to latitude, the provenances showed a progressive increase in xeromorphism towards the north, even though the differences were only minor ones as the whole material represents a displacement of only 3° lat. in that direction. Amongst these morphological properties the number of stomata failed to show any clear trends in respect of either survival or latitude of origin.

The morphological characteristics of the most successful spruce provenance, that from Vallinkangas, lay roughly in the middle of the scale. In terms of latitude, the most northerly provenance possessed relatively large needles, a large number of stomata of a good size and a moderately thick epidermis. This group was also the least successful among the spruce provenances.

The clearest correlation between damage class and the above-mentioned structural properties in the pine saplings was found in the case of the thickness of the epidermal cells ($r = 0.4995^{*}$). This correlation at the 'indicative' level implies that those pine provenances with a thick epidermis were found to be in a better than average condition. No such correlation was to be found in the spruce however, where on the contrary, a highly significant correlation could be found between thickess of epidermal cells and mortality ($r = 0.9503^{***}$).

FACTORS AFFECTING SUCCESS OF THE SAPLINGS

Biotic factors

It has been noted in provenance trials conducted in Finland and elsewhere in Fennoscandia that resistance to fungal infection is better in provenances from localities lying north of the site of the experiment than in those from the study area itself or localities further south, and also that provenances tranplanted to sites resembling their natural habitats are more resistant to the effects of the snow cover (Björkman 1963).

The present experiment showed the specimens from the nearest locality represented, the coastal area of Northern Ostrobothnia at Siikajoki and Raahe, to be the weakest group of all. The principal reason for their demise was *Phacidium infeslans* Karst. Another species found to attack various pine provenances in large numbers after the occurrence of pollution-induced needle damage was *Lophodermium pinastri* (Schrad.) Chev., though this could have had little effect on mortality in spite of its consequences for the condition of the trees. The peak winter for voles in 1973–74 was also a major destructive factor, probably accounting for 2–5 % of the pine sapling deaths that winter. A further significant factor would be the encroachment of grasses into the transplant plot.

Relatively small differences in mortality have been obtained in provenance trials with spruce saplings, though the more northerly provenances have been noted to lack the competitive potential of the southerly ones (Remröd et al. 1972). No differences have been observed in resistance to fungal infection. Correspondingly, no biotic factors were found to affect any of the spruce provenances in the present experiment, though competitive capacity may well have been of some importance, being one reason for the poor performance of the northern provenances.

Abiotic factors

Weather and growing conditions

Soil analyses showed the site to be one rich in nutrients and somewhat typical of arabel land. The pH was moderately high. Little change occurred in these growing conditions during the course of the experiment, the nutrient status of the soil being preserved throughout (Table 5). This high concentration of nutrients is reflected in the rapid spread of grasses to the area and also in the vigorous growth of the saplings.

Two exceptionally warm, dry summers occurred at the beginning of the experiment, while the first winter was exceptionally mild, causing the period of protective snow cover to be of comparatively short duration. Growth began exceptionally early in spring 1975, but the late occurrence of night frosts then led to considerable damage to plants in general. Spruce being particularly susceptible to frosts of this type, this constituted one reason for the death of some spruce saplings. The majority of this damage was concentrated in the period 28.–30. 5. 1975 (see Fig. 6), and was felt both at the pollution damage plot and also at the control plot at Lauttasuo.

All in all, however, the period over which the experiment lasted may be considered quite exceptionally favourable in its weather conditions, and this must have certain consequences for the survival of the saplings (Fig. 7).

Table 5. Hydrogen ion concentration, conductivity and potassium, calcium and magnesium in the soil of the test area.

Taulukko 5. pH, johtokyky ja K, Ca ja Mg-määrä koealueen maassa.

Time *Aika*	pH	Conductivity *Joht. µ S*	mg/l K	 Ca	 Mg	Nitrates *Nitraatit*	Nitrites *Nitriitit*
May 75	4.9	58	126.0	756.1	93.1*	—	—
Toukokuu 76	5.4	24	86.2	730.5	124.5	—	—
June 74	5.2	—	—	—	—		
Kesäkuu 75	5.1	69	142.0	1420.8	90.2*	—	—
76	5.3	33	26.0	491.7	149.4	—	—
July 75	5.2	42	55.3	943.0	100.0*	—	—
Heinäkuu 76	5.9	—	85.3	646.6	225.2	0.604	0.062
August 74	5.5	—	—	—	—		
Elokuu 75	5.5	28.5	192.8	620.1	180.3		
76	5.3	21.0	29.3	874.4	210.3	2.020	0.101
September 75	5.9	37.0	60.6	812.9	187.6	—	—
Syyskuu 76	—	—	91.5	630.1	197.2	1.487	0.087
October 75	5.4	41.5	75.4	701.2	369.7	—	—
Lokakuu							

* Mg without lanthanide adding.

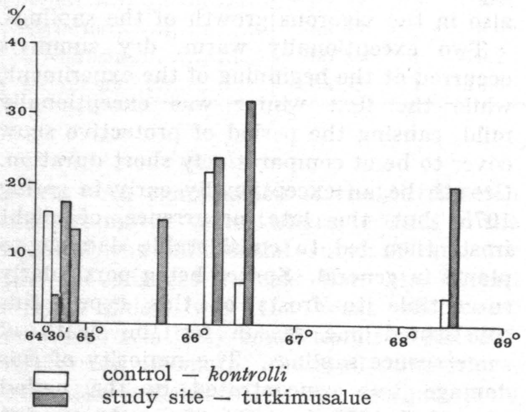

Fig. 6. Damage inflicted upon spruce seedlings by summer frost on 29—30. 5. 1975 at Lauttasuo and the study site proper.

Kuva 6. Keväthallojen (29—30. 5. 1975) aiheuttamat vahingot kuusen taimissa Lauttasuolla ja varsinaisella koealalla.

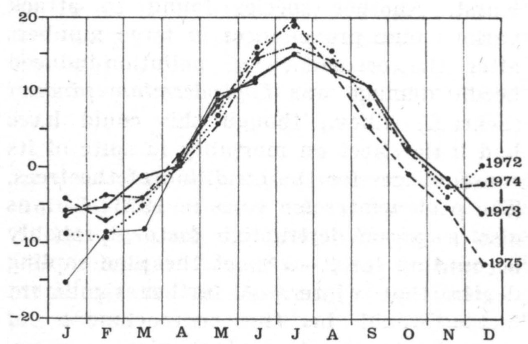

Fig. 7. Mean monthly temperatures at Oulu in 1972—76. The figures suggest that the experiment was carried out during a period of relatively favourable conditions, with mild winters.

Kuva 7. Kuukauden keskilämpötilat Oulussa 1972—1976. Lämpötilat osoittavat tutkimusajanjakson sattuneen suhteellisen suotuisaan ja lämmin talviseen kauteen.

Intensity of air pollution, as judged from symptoms of damage to the vegetation

Typical air pollution damage was seen in the needles of the pine saplings each year, the needles which had grown durıng the summer being polluted in the course of the following winter. There were some individuals which received protection from the snow cover, however, whose needles remained healthy for their first year and suffered damage only in the second. Damage was noted in the first-year needles of practically all the saplings during the winters of 1974—75 and 1975—76. No damage occurred during the summer months, except in August 1975 and 1976, when in both years acute leaf damage was noted in most forest species, principally in the two birch species, *Betula verrucosa* and *Betula pubescens*, and in *Empetrum*. The cause of the damge in 1975 was the high concentrations of nitrogen oxide and sulphur dioxide in the effluent (Kemira 1975), and in 1976, according to measurements made by the Oulu town council, a toxic emission of sulphur dioxide (Aho, personal communication in connection with a conference paper, 25. 10. 1976). At other times the principal cause lay in relatively low longterm concentrations of substances whose combined effects were sufficient to cause damage.

The damage may thus be in general classified as chronic pollution damage, as has been discribed in the same area by

Table 6. Schematic representation of the development of needle injuries during a year (new needles start to develop in June) in test area.

Taulukko 6. Kaavamainen esitys neulasvaurioiden kehittymisestä koekentällä vuoden kuluessa.

Time — *Aika*	Development stage *Kehitysaste*
June — July *Kesä — heinäkuu*	Current year needles remain undamaged, second year needles have the symptoms which have appared during the previous winter. *Kuluvan vuoden neulaset vahingoittumattomia, viime vuotisissa neulasissa vauriosymptomit, jotka ovat syntyneet edellisen talven aikana.*
August *Elokuu*	Current year needles may sustain microscopic injuries near the stomata, visible needle blight in some provenances, some of the previous year's needles fall. *Kuluvan vuoden neulasissa saattaa esiintyä mikroskooppisia vaurioita ilmarakojen lähellä, näkyviä neulasten kärkivaurioita muutamissa alkuperissä, jotkut edellisen vuoden neulasista putoavat.*
October — January *Loka — tammikuu*	Current year needles sustain injuries, previous year's needles develop further injuries. *Kuluvan vuoden neulaset vaurioituvat, edellisen vuoden neulaset saavat lisää vaurioita.*
February — April *Helmi — huhtikuu*	Injuries increase during late winter and spring, their extend depends on the immission dynamics for the year, climatic conditions and resistance of the provenance. *Vauriot lisääntyvät lopputalven ja kevään aikana, niiden määrä riippuu kunkin vuoden imissiodynamiikasta, säädoloista ja alkuperän kestävyydestä.*
May *Toukokuu*	Previous year's needles fall. *Edellisen vuoden neulaset putoavat.*

HUTTUNEN (1975), although it should be noted that the plot used here is located relatively close to the source of the pollution, so that the high concentrations of toxic substances involved lead to a difference in the time required for these substance to take effect compared with the more distant tree damage areas (cf. HUTTUNEN 1975).

The typical needle damage symptoms in pine arose in a slightly different fashion each year, depending on the weather conditions, i.e. prevailing winds, moisture, temperature, ets., and also on the immission dynamics. Other ecological factors may also be observed to exercise some influence upon the extent of pollution-induced tree damage. These include the nutrient status of the plants and their part in the fluctuations in pollution damage noted here and elsewhere (cf. HAVAS 1971, HUTTUNEN 1975. ARONSSON & TAMM 1972). The dependence of the occurrence of tree damage on certain such factors is depicted in Table 6, and the relative importance of the snow cover as a protective element is examined in Fig. 8. The snow cover does not in fact appear to play any decisive role in the fate of the pine under air pollution conditions, for those specimens which enjoyed the best snow cover did not necessarily fare particularly well, although it was of a certain significance in relation to the occurrence of pollution damage symptoms and the incidence of biotic damage factors. In the spruce, however, it was apparently a crucial factor, particularly as regards the occurrence of needle damage symptoms, extremely few of which were to be noted in the spruce specimens, which were generally entirely covered beneath the snow for several months each year.

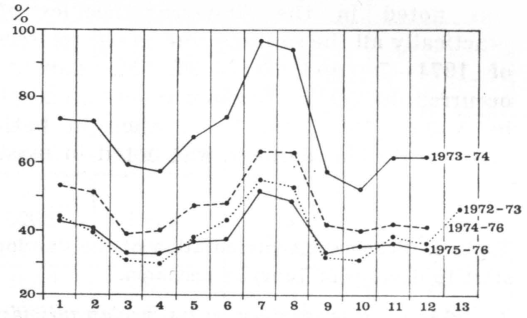

Fig. 8. Correlation between depth of protective snow cover and condition of the seedlings. 1 — most successful provenance, 13 — provenance died off completely.

Kuva 8. Männyn taimien saama lumisuoja suhteessa taimien viihtyvyyteen, numero 1 parhaiten viihtynyt ja numero 13 kokonaan kuollut alkuperä.

DISCUSSION

General

The field experiments suggest that the success of the various Scots pine and Norway spruce provenances in the Oulu air pollution zone is clearly to be associated with the general trends to be notes in the survival of different provenances of this species in Northern Finland and elsewhere in Fennoscandia. It is normally found that sapling deaths are more common in the pine than the spruce, and that pine will tolerate transplantation less well than spruce. The more northerly provenances tend to resist disease better than the southerly ones in the pine, but no corresponding pattern emerges in the case of the spruce (BJÖRKMAN 1963).

As far as the resistance of pines to abiotic pollution factors is concerned, the more northerly provenances, which are more hardy in respect of the cold winters, also seem to survive air pollution more successfully. This also holds good in as far as it affects the needle morphology of the various provenances, in connection with which VOLG & BÖRTITZ (1965) observe that »the difference in sensitivity is not of a physical nature and is not caused by differences in anatomy and morphology. Differences in resistance, however, may well be coupled with morphological properties.» In the

Table 7. Damage symptoms in pine needles examined on 16. 9. 1976 (damaged in late August by SO_2 effluent).

Taulukko 7. Vauriosymptomit männyn neulasissa syksyllä 1976, 16. 9. 1976 tehtyjen havaintojen mukaan (vauriot syntyneet elokuun lopussa).

Provenances from S to N *Alkuperät etelästä pohjoiseen*	Damage at the microscopic level *Mikroskooppiset vauriot*	Visible injuries näkyvät vauriot *Injured needle area vaurioitunut neulaspinta-ala*	Percentage of damaged needles *Vaurioituneita neulasia %*	Area of damage *Vaurioitunut neulaspinta-ala*	*Percentage* of needles damaged *Vaurioituneita neulasia %*
Pyhäntä 64°10'	Mesophyll injured near stomata *Solut vaurioituneet ilmarakojen lähellä*	none ei	—	1/3 — 1/1	90 %
Kuhmo 60°20'	Mesophyll injured *Mesofyllin solut vaurioituneet*	0 — 1/3	25 %	1/3 — 1/1	100 %
Vihanti—Rantsila 64°30'	Mesophyll cells injured near stomata *Solut vaurioituneet ilmarakojen lähellä*	none ei	—	1/3 — 1/1	100 %
Hörnefors Sweden 64°30'	Mesophyll cells injured near stomata *Solut vaurioituneet ilmarakojen lähellä*	none ei	—	1/3 — 1/1	100 %
Vaala 64°40'	Mesophyll cells injured near stomata *Solut vaurioituneet ilmarakojen lähellä*	none ei	—	1/2 — 1/1	100 %
Puolanka 64°50'	Several injured mesophyll cells near stomata *Useita vahongoittuneita soluja ilmarakojen läheisyydessä*	Yellow tips to needles neulasissa keltaisia kärkiä	Some Muutamia	1/3 — 1/1	100 %
Ylikiiminki 65°10'	Mesophyll cells injured near stomata *Solut vaurioituneet ilmarakojen lähellä*	none ei	—	1/3 — 1/1	70 %
Pudasjärvi 65°37'	Mesophyll cells injured near stomata *Solut vaurioituneet ilmarakojen lähellä*	none ei	—	1/5 — 1/2	100 %
Ylitornio 66°22'	Mesophyll cells injured near stomata *Solut vaurioituneet ilmarakojen lähellä*			1/3 — 1/1	100 %
Pello 66°45'	Mesophyll cells injured near stomata *Solut vaurioituneet ilmarakojen lähellä*			1/3 — 1/1	70 %
Kolari 67°16'	Clorophyll cells of stomata injured *Ilmarakojen klorofyllisolut vaurioituneet*				
Kittilä 67°40'	Clorophyll cells of stomata injured *Ilmarakojen klorofyllisolut vaurioituneet*				

present experiments we are inded concerned with differences in resistance, and needle xeromorphism and thickening of the epidermis constitute factors which enhance survival. Corresponding observations are made by *Haedicke* (1969) in *Larix decidua* and *L. leptolepis*, in which »clones with wavy needles were more resistant than clones with straight needles».

The study of the acute needle damage symptoms occasioned by air pollution will alone suffice to demonstrate that the lowest incidence of damage symptoms occurs in that provenance which possesses the most pronounced xeromorphism (cf. Table 7). No corresponding pattern could be detected in the spruce, where the overall incidence of needle damage symptoms was in any case very much lower. This is most probably due to the fact that these saplings enjoyed the protection of a good snow cover every winter. Where there were cases of needle damage, these occurred only at the tips of the saplings, and were due to the effect of frost, which is distinguishable from that of pollution in fresh samples under the microscope. No damage symptoms at all developed in the needles of the spruce saplings in the summers of 1975 and 1975. This need not necessarily imply a greater resistance to pollution on the part of this species, but may simply be connected with the better mechanical protection it received at this site.

Significance of winter for pollution damage

One clear outcome of the experiment was the observation that a very much greater amount of tree damage is caused during the winter than during the summer, two important factors in the incidence of damage being the weather conditions and the immission dynamics. Chronic damage occurred regularly every winter, usually arising in the middle of the winter, but becoming visible only in the spring, though occasionally this even became visible in mid-winter if if weather conditions permitted.

Corresponding findings concerning winter tree damage are reported by MATERNA (1974) in the mountain areas of Czechoslovakia, nothing that such damage is to be seen in transplanted saplings within a few weeks in mid-winter, whereas others transplanted to similar sites in an unpolluted area remain healthy. He similarly mentions that during the winter very much smaller concentrations of pollutants suffice to cause tree damage compared with summer conditions.

Earlier discussions on the nature of winter tree damage appear in the papers of BÖRTITZ (1964, 1965, 1967), in which he sates that SO_2 affects the assimilation process even in dormant trees, while rapid alternations between mild and frosty weather may produce the combined effects of SO_2 and frost. It has also been possible to show by means of isotope experiments that an accumulation of sulphur develops in the needles even during the winter, a finding which is also corroborated by the results of earlier micro-analyses (HUTTUNEN 1973, 1975).

No appreciable accumulation of fluorine was noted during the period of the present experiment, but the contribution of the oxides of nitrogen remains impossible to estimate, as the determination of total nitrogen present has proved an inadequate criterion for these purposes.

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SELOSTE:

ILMAN SAASTUMISEN VAIKUTUS MÄNTY- JA KUUSIALKUPERIEN VIIHTYMISEEN POHJOIS-SUOMESSA

Oulussa ilman saasteiden vaivaamalla puustovaurioalueella seurattiin eräiden Pohjois-Suomen mänty- ja kuusialkuperien viihtymistä vuosina 1972—1976. Männyn taimista menestyivät parhaiten pohjoiset ja itäiset alkuperät ja kuusista tutkimuspaikkakunnan läheisyydestä kotoisin olevat alkuperät. Tehdyn kokeen tulokset olivat samansuuntaisia kuin muissa vastaavissa kokeissa, mutta taimien kuolleisuus oli poikkeuksellisen korkea ja taimien kuntoluokituksessa oli todettavissa hyväkuntoisten ja terveiden taimien vähyys.

Eri alkuperien välillä oli havaittavissa rakenteellisia saasteresistenssiin viittaavia ominaisuuksia kuten neulasten kseromorfisuus tai paksu epidermi. Ilman saasteiden aiheuttamien talvivaurioiden todettiin olevan taimikuolleisuuden suurin syy, kesäaikana syntyneet vauriot jäivät suhteellisen vähäisiksi.

Kokeen tuloksia voidaan käyttää hyväksi valittaessa kotimaisia havupuun taimia kaupunki- ja teollisuusympäristöjen istutuksiin.

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